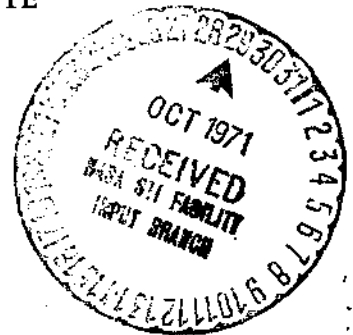


NTIS: HC # 3.25

Final Report Orbiting Propellant Depot Safety Volume I: Management Summary Report

Prepared by ADVANCED VEHICLE SYSTEMS DIRECTORATE
Systems Planning Division

20 SEPTEMBER 1971



Prepared for OFFICE OF MANNED SPACE FLIGHT
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
Washington, D. C.

Contract No. NASW-2129



Systems Engineering Operations
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NASA CR 123385	30
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FINAL REPORT
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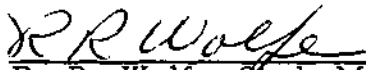
FINAL REPORT

ORBITING PROPELLANT DEPOT SAFETY

Volume I: Management Summary Report

Prepared by Advanced Vehicle Systems Directorate

Approved by



R. R. Wolfe, Study Manager
Director
Operations Office
Advanced Vehicle Systems
Directorate
Systems Planning Division



S. M. Tennant
Assistant General Manager
Systems Planning Division
Systems Engineering Operations

The information herein is tentative and is subject to modification. Initial distribution of this document is confined to persons and organizations immediately concerned with the subject matter.

PREFACE

This study was initiated as Subtask 3, Orbiting Propellant Depot Safety Study of NASA Study C-II, Advanced Missions Safety Studies. Other studies in this series are: (i) Subtask 1, TNT Equivalency Study, Aerospace Report No. ATR-71(7233)-4; and (ii) Subtask 2, Safety Analysis of Parallel versus Series Propellant Loading of the Space Shuttle, Aerospace Report No. ATR-71(7233)-1.

The study was supported by NASA Headquarters and managed by the Advanced Missions Office of the Office of Manned Space Flight. Mr. Herbert Schaefer, the Study Monitor, provided guidance and counsel that significantly aided this effort.

Study results are presented in three volumes; these volumes are summarized as follows:

Volume I: Management Summary Report presents a brief, concise review of the study content and summarizes the principal conclusions and recommendations.

Volume II: Technical Discussion provides a discussion of the available test data and the data analysis. Details of an analysis of possible vehicle static failure modes and an assessment of their explosive potentials are included. Design and procedural criteria are suggested to minimize the occurrence of an explosive failure.

Volume III: Appendices contains supporting analyses and backup material.

ACKNOWLEDGEMENT

The principal participants of The Aerospace Corporation in this study were:

M. Donabedian	Semimodular/Modular Concept Development and Analysis
R. P. Toutant	Docking/Transfer Interface Concept Development and Analysis
R. R. Wolfe	Study Manager and Director, Operations Office Advanced Vehicle Systems Directorate
H. H. Yoshikawa	Integral Concept Development and Analysis

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1. INTRODUCTION

Under consideration, are orbital missions that require the use of vehicles other than Space Shuttles, e. g. , a cislunar shuttle, that is either chemically or nuclear propelled, space tugs functioning as shuttles which can service orbiting payloads or vehicles. Such vehicles may be spaced-based. In this operational mode, the vehicles would be stationed in a low earth orbit from which they would initiate and terminate flights. The only time these vehicles might return to earth would be for major maintenance.

The flight frequency of these vehicles indicates that large quantities of propellants will have to be delivered to them in orbit. Orbiting propellant depots, in both geocentric and selenocentric orbits, are being considered as candidate methods of making the required propellants readily available. Therefore, as an initial part of the evaluation of this concept, an assessment of the potential safety hazards associated with the operation of such a depot (OPD) is desirable.

2. STUDY OBJECTIVE AND CONSTRAINTS

2.1 OBJECTIVES

The objective of this study was to provide safety guidelines and requirements for the operation of an Orbiting Propellant Depot.

2.2 CONSTRAINTS

Because conceptual configurations of the OPD were not to be, and have not been, developed in depth, this study was limited to a top level qualitative safety analysis of the gross depot requirements. However, certain orbiting vehicle (OV) concepts had to be taken into consideration, such as a Space Shuttle that would be launched from earth by a booster stage and carry orbiting vehicle(s) such as (a) change-of-plane shuttles, (b) tugs, or (c) other vehicle which might be maintained and/or refurbished in (geocentric) orbit or might be returned to earth for same.

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3. RELATION TO OTHER NASA EFFORTS

This study provided safety-related criteria which will be useful in assessing configuration proposals for OPD. The criteria will provide safety guidelines and requirement inputs for future system design tasks and a baseline against which design progress can be weighed relative to safety.

4. METHOD OF APPROACH

The general plan followed in this study included:

- a. Development of conceptual orbiting propellants depot configurations.
- b. Assessment and comparison of conceptual gross levels of safety.
- c. Establishment of recommendations as to safety requirements and criteria for normal and emergency operations.

5. RESULTS

5.1 GENERAL

This study is applicable to an Orbiting Propellants Depot (OPD) located in geocentric or selenocentric orbits. Since there was no firm design approach, three configurations were examined in an effort to bracket the design concepts. In the three concepts studied, the OPD was posited as being unmanned and the user or resupply vehicle as manned.

Propellants for the OPD would be delivered by a space shuttle to an OPD in geocentric orbit; however, an additional flight would be required to deliver propellants to an OPD in a selenocentric orbit.

5.2 CONCEPTS

The distinguishing features of the three concepts are discussed in the following paragraphs. A comparison of the concepts, indicating advantages and disadvantages, is given in Table 1.

5.2.1 Integral

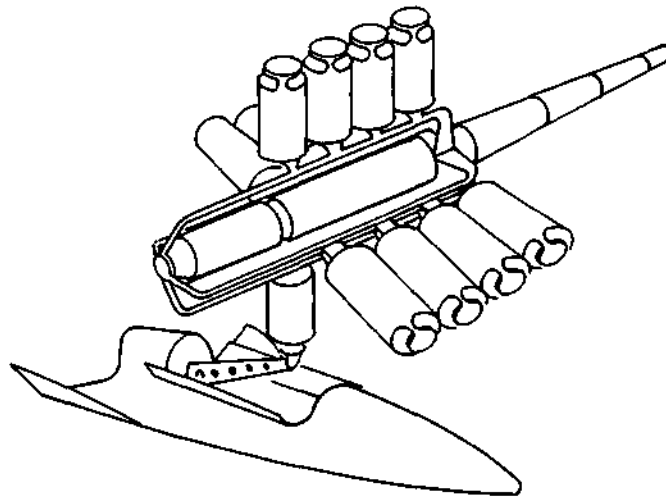
In the integral concept, the propellant storage tanks form a permanent part of the primary structure of the OPD. All propellants received or dispensed by the OPD must utilize the OPD propellant transfer subsystem.

5.2.2 Semimodular

In the semimodular concept, as shown in Fig. 1, a central core contains all subsystems required for operation of the OPD. Arranged around the core is a series of docking ports which accept modularized propellant storage tanks for resupply of the OPD; empty tanks are returned to earth by a resupply OV and are recycled. The concept is similar to the integral concept with respect to the dispensing of the propellants.

Table 1. Orbiting Propellant Depot Concepts

Concept			Advantages	Disadvantages
OPD	OPD Resupply Technique	Receiver Vehicle Resupply		
Integral	Modular	Propellant flow	<ol style="list-style-type: none"> 1. OV separate during propellant operation 2. OV not affected by OPD instability 	<ol style="list-style-type: none"> 1. Two docking sequences required per resupply 2. Requires propellant flow plus tank exchange
	Fuel transfer probe	Propellant flow	<ol style="list-style-type: none"> 1. Eliminates hard docking of OV with OPD 2. Unstable OPD operation has minimal impact on OV 	<p>Propellant transfer line vulnerable to unstable OPD</p>
Semimodular	Modular	Propellant flow	<ol style="list-style-type: none"> 1. No propellant flow during resupply 2. No propellant phase control required during resupply 	<ol style="list-style-type: none"> 1. Two docking sequences per resupply 2. Complex manifolding system required
Full Modular	Modular	Modular	<ol style="list-style-type: none"> 1. No propellant flow required 2. No propellant phase control required 	<ol style="list-style-type: none"> 1. Two docking sequences per resupply 2. Requires more critical maneuver during tank exchange
	Modular with OPD-mounted boom	Modular	<ol style="list-style-type: none"> 1. No propellant flow required 2. Single docking sequence 	<ol style="list-style-type: none"> 1. Improper boom operation can cause tank/OV damage 2. Hard dock required 3. OPD unstable during tank movement



CHARACTERISTICS

- i MODULAR OPD WITH CENTRAL MANIFOLDING AND SUBSYSTEMS
- ii MODULAR RESUPPLY WITH INTEGRAL TRANSFER TO USER VEHICLE

Figure 1. Semimodular Concept

5.2.3 Modular

The modular concept is similar to the semimodular concept both in configuration and method of resupply, i. e., a central core to which the propellant modules are docked (Fig. 1). It differs from the integral and semimodular concepts in that no fluid flow is required to dispense propellants. The user OV being serviced exchanges its empty propellant tanks for full tanks. The empty tanks would be stored at the OPD until they were returned to earth by a resupply OV for recycle.

5.3 HAZARD ANALYSIS

The analysis considers operational sequences in which personnel are subjected to safety hazards. These events could occur in two main operational phases:

- a. OPD resupply
- b. Propellant transfer from the OPD to a user OV

Top-level failure mode and effect analyses were performed for the major events occurring in these phases. NASA hazard categories, ranging from catastrophic to negligible, were used to grossly classify those of the study.

As each hazard was evaluated, preventive and remedial criteria were developed. Preventive criteria are meant to be utilized as inputs to design and operations documents to prevent or minimize the possible occurrence(s) of the failure(s). Remedial criteria suggest contingency or backout procedures to be employed after a failure has occurred. Tables 2 and 3 contain typical examples of hazard analyses.

Table 2. Typical Modular Resupply Hazards (common to all concepts)

Hazard Category	Failure Mode	Effect of Failure	Preventive	Remedial
Catastrophic	Tank or vehicle damage during transfer of tank to OPD	Propellant spillage with potential fire or explosion	Impact absorbing system built into deployment mechanism	
Critical	Deployment mechanism stuck in open position with full tank	No fuel transfer and critical reentry problem	<ol style="list-style-type: none"> 1. Redundant mechanism 2. Manual override system by OV 3. Tank jettison 4. Fuel dump provisions 	<ol style="list-style-type: none"> 1. EVA to correct system 2. Dump fuel 3. Jettison tank
Marginal	Cannot connect full tank to OPD properly	No fuel transfer	Redundant docking ports	Dump fuel and return to earth
Negligible	Inability to detach empty tank from OPD	Degradation of OPD resupply capabilities	Provide redundant dock ports with additional empties	Return to earth without empty tank(s)

Table 3. Typical Propellant Transfer Hazards (common to integral and semimodular OPD concepts)

Hazard Category	Failure Mode	Effect of Failure	Preventive	Remedial
Catastrophic	Improper mating. LO ₂ /LH ₂ disconnections crossed	Mixing of propellants in user vehicle, probable fire or explosion	<ol style="list-style-type: none"> 1. Use unique fittings on LO₂/LH₂ interfaces 2. Use signal check-out prior to transfer 	Separate vehicles and redock
Critical	Leakage of interface fittings	Propellant leakage, potential fire or explosion	<ol style="list-style-type: none"> 1. Propellant transfer in well vented area 2. Provide sensors and purge gas for enclosed areas 	<ol style="list-style-type: none"> 1. Activate purge system 2. Terminate transfer and separate vehicles
Marginal	Power failure in OPD	Transfer suspended	<ol style="list-style-type: none"> 1. Redundant power unit in OPD 2. Capability to transfer to user OV power 	Switch to user OV power
Negligible	OPD relief valve fails to open during transfer	Loss of pressure transfer impaired	<ol style="list-style-type: none"> 1. Redundant relief valve 2. Relief ISO valve controllable by user OV 	Actuate relief ISO valve

6. CONCLUSIONS AND RECOMMENDATIONS

6.1

CONCLUSIONS

1. The semimodular depot concept appears to be the safest and operationally the most flexible of the configurations analyzed.
2. A completely open-structured depot is desirable, i. e., no pressurized areas other than the storage tanks; where enclosed areas cannot be avoided, the capability to purge these areas is desirable.
3. Coaxial propellant transfer lines or parallel loading of propellants is not recommended.
4. Positive identification of LO_2/LH_2 transfer interfaces is required.
5. Unique fittings should be used at the LO_2/LH_2 transfer interfaces to preclude cross coupling of the propellant tanks.

6.2

RECOMMENDATIONS

1. Studies of flame propagation and explosive phenomena in space would be valuable in the event that the results of this study are to be expanded.
2. The explosive studies should address the problem of possible failure because of debris following an explosion.

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Internal

Bello, M.
Donabedian, M.
O'Brien, N. R.
Sitney, L. T.
Steinman, J.
Toutant, R. P.
Willens, D.
Wolfe, R. R.
Yoshikawa, H. H.

External

NASA Scientific and Technical (3)
Information Facility
P.O. Box 33
College Park, Maryland 20740

NASA Headquarters
Washington, D.C. 20546
Attn: New Technology Representative
Code: UT

NASA Headquarters
Washington D.C. 20546
Attn: Code: MTE (50)

SAMSO(XRZT)
Air Force Unit Post Office
Los Angeles, Calif. 90045
Attn: Lt Col R. S. Bearman (2)